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A general approach toward building integrated photovoltaic systems and its implementation barriers: A review

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ABSTRACT

Building integrated photovoltaic (BIPV) systems is one of the most promising technologies and has recently experienced extraordinary growth. There is a huge consensus that these advancements lead to novel methods for domestic energy generation. Technical improvements, governmental supportive laws and financial aids are some of the contributors to this development. However, the proportion of solar power production as compared to conventional electricity generation methods is still negligible and needs more dedication. In this study, a large number of previous research works have been reviewed and reasons and solutions for BIPV success or failure are discussed.

Contents

1. Introduction

Clean energy is one of the world's fast-growing sectors. Nowadays, everyone is familiar with greenhouse gases and resulted environmental damages. It is crystal clear that, greenhouse gases are about to increase rapidly due to human activities, leading to global warming which is strongly perilous and devastating. Furthermore, it cannot be denied that some nations are not enjoying the presence of electrical power. At this time over 1.4 billion people in the world are deprived of electricity [1]. As a result of rapid population and industrial growth, we have to generate incredibly more electricity in the future. Besides, the cost of electricity produced using fossil-based fuels in different ways is gradually increasing. At this time around 80% of world's energy generation depends on fossil-based fuels [2]. Different studies predicted that oil production industry would pass the

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turning point and will no longer be able to meet our needs by the end of 2012 [3], 2014 [4], or 2015 [5]. Moreover, the Fukushima Daiichi nuclear disaster on 11th March 2011 reminded us the importance of a secure and clean energy source and the attention should be shifted more to renewable energy sources.

Hence, all renewable energy sources should be developed and deployed for our future consumption and to mitigate environmental issues. To illustrate this, in 2006 around 12% of total electricity need in Germany was fulfilled by renewable energy sources and led to reduction of over 100 million tons of carbon dioxide emissions [3]. Fig. 1 shows the trend in CO_2 emissions from fossil fuel combustion during 1870–2008. Both direct and indirect CO_2 emissions in EU countries are shown in Fig. 2.

The overall approaches toward photovoltaic (PV) application also have changed a lot in recent years. In the early stages, only small PV cells were studied but today great attention has been shifted to solar concentrated power and large scale grid-connected PV systems [8]. Currently more than 90% of PV systems worldwide are utilized as grid-connected systems [9] and significant part of this percentage belongs to BIPV projects.

PV cells can be installed either on rooftops or other parts of buildings such as walls, balcony or window glasses. This installation is called building integrated photovoltaic or in short form BIPV [10,11]. Fig. 3 shows a common BIPV system installed in Freiburg, Germany [12]. Building-Applied-Photovoltaic (BAPV) is another term used for PV systems which are integrated into buildings after finishing construction. Since this term is not so common and there is no necessity to differentiate between these two terms, in this paper, BIPV is referred generally to all cases. Today's buildings are responsible for more than 40% usage of total energy and 24% of total greenhouse gases emissions [13]. In Malaysian Building Integrated Photovoltaic project (MBIPV), greenhouse gases emissions were reduced by 65,100 t CO_2 during the period of 2005–2010 [14].

In this paper, the aim is to review previous studies of BIPV in order to discuss and categorize its barriers and their proposed solutions and finally summarize their associated pros and cons. This review will address related issues on applications of PV cells

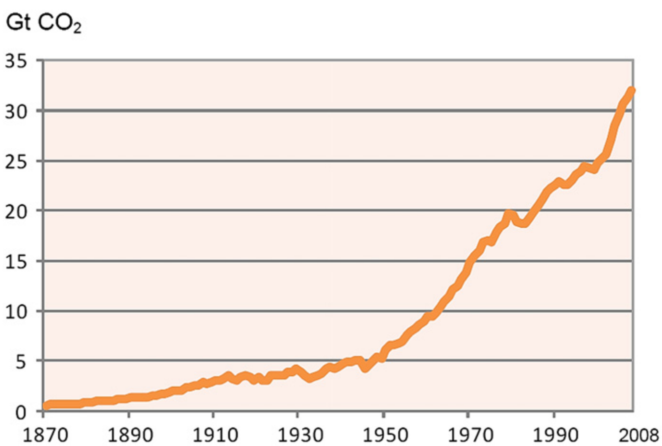

Fig. 1. Trend in CO_2 emissions from fossil fuel combustion [6].

Fig. 3. Solar settlement in Freiburg [12].

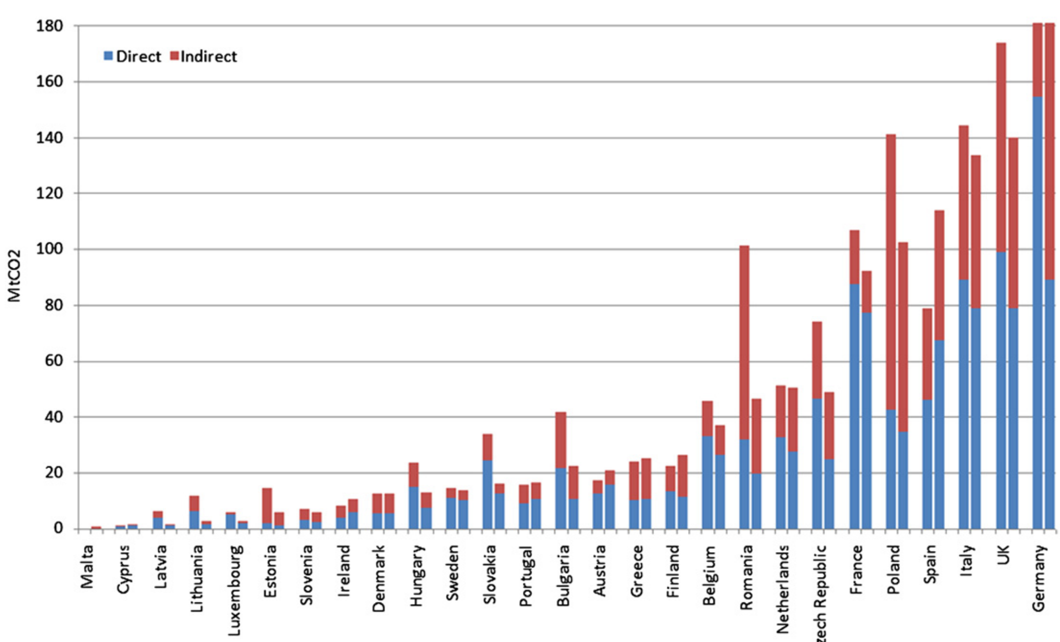

Fig. 2. CO_2 emissions in EU countries (1990, 2008)[7].

in grid-connected systems and the popularity to growth rate of PV in recent years and its future prospects.

2. Classification of problems

The Earth's surface approximately obtains 100.000 TW solar power through radiation [15]. By only transforming 1% of this solar radiation, a great amount of energy could be generated [16]. The BIPV systems have introduced a lot of advantages as described further.

First of all, solar radiation is free and infinite, almost accessible everywhere without any polluting waste or side effects and harms to the global climate. Furthermore, installation, operation and maintenance of the solar panels are not relatively difficult and expensive [17]. Moreover, since solar energy generators are normally located near the customers, there is no need to construct further transmission lines. Therefore, financial resources can be saved and power losses in distribution networks and security risks are minimized. Also, there is no need to construct more major power plants due to the fact that renewable sources can be utilized as emergency suppliers. In addition, solar energy can help the main network during peak load hours and shares the heavy burden [18,19].

The power generated by the sun is still insignificant as compared to other types of power production techniques, but unquestionably the recent growth (1996–2006) cannot be ignored [20]. In the past 5 years, the world experienced more than 150% growth in PV production [16]. For example during the last decade, European photovoltaic companies have reached an average annual production of 40% and in 2005, global solar markets earned 11.8 billion dollars which is up 55% more than 2004 figures. The ultimate goal is to double the existing efficiency in order to skyrocket clean energy production [9]. The International Energy Agency (IEA) predicts that solar systems will produce one fifth of the whole global energy by 2050 and anticipates 60% rise by the end of this century [21]. Table 1 presents annual rate of grid-connected PV implementations in the whole market [22].

Although we can see this significant rise of tendency toward solar systems around the world, but a lot of problems have to be solved if we want to keep this trend. In this review, we have classified the barriers into four main groups:

1. Institutional barriers
2. Public acceptance
3. Economic barriers
4. Technical barrier

2.1. Institutional barriers

By making strong permanent supportive policies and plans, governments can empower these programs. Sometimes these plans can entirely revolutionize the situations and open up new channels. For instance, Spain's encouragement of renewable energies was confirmed in 1999 but the big evolution did not happen until 2005 when the promotion of renewable energy (PER) was planned. Consequently after Germany, Spain holds the second position in EU ranking in the year 2009 [23].

Through our reviews, it can be inferred that almost none of the goals which were set for wind power prosperity were achieved in the Netherlands due to lack of satisfactory agendas [24,25]. Some different articles describe strong institutional policies as the most important factors in developing BIPV or rooftop solar PV systems [23,26–29].

Tariff is among significance elements in a grid-connected PV system. Two different tariffs can be defined in these systems. The first one is buying tariff and the second one which is more important is Feed-in Tariff (FiT). Specially for BIPV project, FiT is one of the most or maybe even the most important factor [30]. FiT which is sometimes called Advanced Renewable tariff or Renewable Energy Payment is guideline procedures planned to facilitate investments in renewable energy. FiT suggests a long-term financial permanence, tariff digression and risk reduction to encourage investors financing in this field.

National Renewable Energy Laboratory (NREL) reported that these factors should be considered in a successful FiT policy: steadiness, long-term contracts, reasonable energy prices, annually decreasing payments, FiT incorporation into the electricity rate and reduced official procedures [31].

In [21,32], governmental activities, policies, goals and their investments and improvements in past decades in both leading and developing countries such as Spain, Germany, USA, Japan, China and Malaysia are discussed and it was concluded that many different and strong incentives and supports should be provided to maintain progressive programs on the right track. For instance, US officials are trying to provide employment for more than 150,000 individuals in solar industry by the year 2030 and continue to allocate reasonable investments in the nation's intellectual and research centers, laboratories, universities and other establishments.

In [33], the organizations who are responsible for energy planning and providing in some Middle Eastern and North African countries such as Morocco, Algeria, Egypt, Palestine and Lebanon—which actually receive abundant solar radiation—are discussed. Furthermore, a comprehensive database of the potentials, goals, foreign and governmental supports and investments on solar systems for each country has been gathered and fully described. It is advised to carefully explore the nationwide programs that are running in these countries which give us new insights about energy policies. For example, the PPER program (Pilote de Pre-Electrification Rurale) which was the first attempt in off-grid rural electrification with the goal of providing electricity for 240 villages in three different provinces in Morocco was discussed in this paper. The Ministry of Energy and Mines in cooperation with the Ministry of Interior and Renewable Energy Development Centre undertook this project based on Moroccan-French financing pattern.

In many studies [8,34–36], it is acknowledged that defining a good FiT policy is one of the most important keys to incredible growth of PV markets in Germany and many countries adopted the German FiT [3]. Specially in Malaysia, the FiT has recently been created based on Germany's experience [34,37]. The FiT scheme started on 2011 and the cumulative installed capacity of 1.250 MW was defined as the main goal for 2020. In this scheme, additional benefits are considered as incentives for BIPV systems [38].

The German Renewable Energy Sources Act or EEG (Erneuerbare-Energien-Gesetz) guarantees the fixed tariffs for electricity injected

Table 1
Worldwide annual rate of grid-connected PV implementations [22].

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Annual growth rate (%)	7.9	21.3	23.5	29.9	41.7	50.4	51.4	55.5	65.9	~70	~75	~80

into the grid for 20 years and the year which it was put into operation. The payment depends on the defined tariff in the year the equipment was installed [3]. Another innovation in EEG was the degression of tariff. In this mechanism, since reduction of total cost is predictable in this field, the rates for new projects also decline annually. The amount of degression is varied in different technologies such as wind, solar or etc.

Being so prosperous, Germany has become an idol in this field. Mabee et al. [35] applied a thorough comparison between FiT issue in Germany and Ontario to learn some lessons from Germany experiences and try to optimize the FiT in Ontario. First, the German Government has more commitment to achieve pre-planned goals and even accomplishes beyond that regardless of political changes. Secondly, investors are reassured and motivated because of the model of degression that has been adopted for long-term purposes.

It is essential to bear in mind that the supportive policy should be continuous and long-term; otherwise it might result in boom-and-bust cycles which could be destructive for investors' trust and confidence [38].

In Walker's study [39], the impact of FiT on United Kingdom's capability of generating electricity in renewable energy type is analyzed with Green-X software to see whether generating 5 MW by 2020 is an achievable goal or it is too optimistic and if current FiT scheme is appropriate or not. He came up with the idea that policy assessments need to be restructured at appropriate intervals to be adjusted to cost fluctuations.

Uran and Krajcar [40], optimized their previous method which was based on geometric Brownian motion by implementing mean reverting process from Blanco and Soronow to calculate the frugal ratio of a cogeneration unit. The main goal of this attempt is to compare the support mechanism in Croatia and some EU members, and also define a new FiT which is necessary to be corrected each year.

Trypolska [41] reviewed and presented the positive effects and significance of defining a suitable FiT to enhance rapid growth of green energy especially in solar sector in Ukraine.

Ritger and Vidican [42], made an attempt to predict the future cost and price of small-scale photovoltaic systems and based on this prediction, they tried to define the best FiT for next years.

Being an island country totally depends on importing fossil fuels for power generating, Taiwan has a strong determination for investing on renewable energy. Huang and Wu [43] thoroughly discussed the FiT policy, its importance, calculation methodology and troubles on the way and recommended some solutions like elimination of non-financial barriers, preparing more economic sources to prevent the project of being entirely reliant on governmental aids.

Chua et al. [34] explored the potential of different types of renewable energy and different governmental policies such as Fifth Fuel Policy (2000) which was mentioned as the most influential policy, National Biofuel Policy (2006) and National Green Technology Policy (2009) in Malaysia. In addition, history of FiT in Malaysia since the introduction of Small Renewable Energy Power (SREP) program in 2001 and the new FiT policy which was presented in National Photovoltaic Conference in 2009 are discussed in their work.

Couture and Gagnon [30] reviewed different FiT payment models for generated electricity by renewable sources and specifically mentioned the benefits of fixed price and market-independent method in encouraging and assuring the investors of roof top PV projects.

Liu et al. [44] put forward the FiT in Queensland and mentioned that the FiT was put to practice on first of July in 2008 with a noticeable price of 44 cents.

Sharma et al. [45] looked into a number of governmental supportive policies and their specific aims to promote solar energy in India during past years including: Electricity Act 2003, National Electricity Policy 2005, National Tariff Policy 2006, National Rural Electrification Policies (NREP), initiatives to promote solar PV in India, Semiconductor Policy (2007), solar PV generation based incentive, and research and development (R&D) initiatives.

One of the most inclusive studies [46], shed light on the procedures of defining FiT in Serbia. Besides, we can discover FiT calculation methods for other European countries like Germany. It also presents valuable information about estimation of the budget that we have to put aside for BIPV projects. It is suggested that today's FiT (0.23 €/kWh) is not right at all.

First of all, in 12 years program which was used before in Serbia, FiT should be constant at the value of 0.53 €/kWh.

Secondly is to utilize increasing FiT type with 0.21 €/kWh initiating price and continue to increase this payment with increasing price rate of grid electricity [41].

Del Río and Gual [47] recounted different methodologies in formulating and describing FITs and then specifically introduced the Spain FiT.

Defining applicable and suitable standards and removing unnecessary bureaucratic steps should also be considered as important factors in success of BIPVs and these decisions are also in governments' jurisdiction.

At the end of this part, first, BIPV and then status of general PV market in some advanced regions of the world in this field such as Europe, East Asia and North America are reviewed.

Fig. 4 shows the current BIPV installed systems in the world and some prediction for its future expansion [48]. Besides that, Fig. 5 shows the development status of different countries in BIPV market.

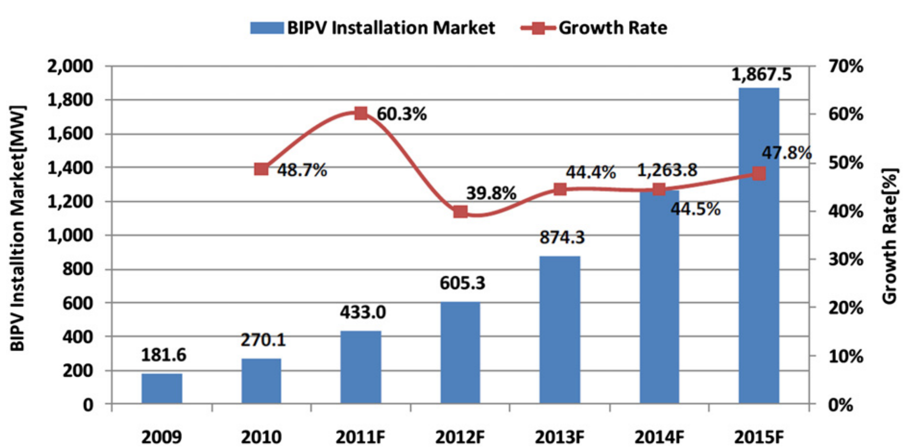

Fig. 4. Global BIPV installation and prediction of its expansion rate [48].

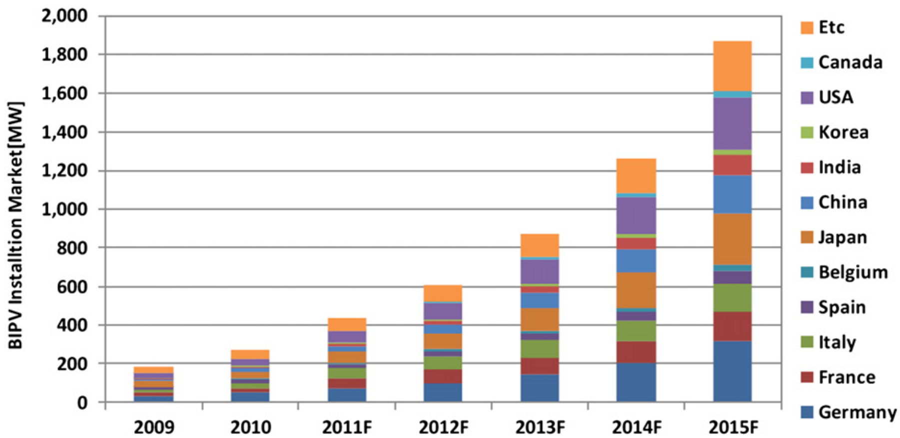

Fig. 5. Development status of different countries in BIPV market and their future progress [48].

In Europe region, based on the report of European Photovoltaic Industry Association in the year 2012 [38], although Germany lost the top growing market to Italy on 2011, this country is still the biggest PV market in the world. In the year 2011 Germany added 7.5 MW to its previous installation while Italy did almost 9.3 MW and experienced an astonishing growth in the time. The FiT plays a significant role in this achievement (€5.5 billion per year). About half of the PV installations in the world are installed in these two countries. France is the third European country which managed to add more than 1 GW to its market. Fig. 6 shows the market share for Europe in the year 2011 and Fig. 7 shows the growth of cumulative installed capacity for 11 years (2000–2011).

In Asia Pacific region, around 2.2-GW capacity was added to China's previous installations and this is the biggest growth outside Europe. It definitely took the first rank in PV market outside Europe [38]. At the same time, China is the biggest PV module producer in the world as well. According to [49], China aimed to produce 300 MW in 2010 but this target has already been achieved in 2009. Their current goal is to reach 5000 and 20,000 MW in 2015 and 2020 respectively.

Another country, Japan, through Japanese authorities, they announced their plan with the target by the end of 2030, 40% of their electricity demand should be generated by renewable energy sources. Specifically in the year 2011, around 1.3 GW new PV systems were installed and their target for 2020 is 28 GW [38].

In North America, as mentioned in [38], United States almost doubled its PV systems capacity by adding 1.9 MW in the year 2011 which made the market was around 4.4 GW. Canada was observed with a significant growth up to 340% during 2011. The importance of FiT's role is proved again here, since around 85% of this new capacity installed in the province of Ontario is due to effective FiT.

Fig. 8 shows the current status of PV market in the world and global cumulative installed capacity is shown in Fig. 9.

2.2. Public acceptance

Success or failure in BIPV projects totally depends on civilians' cooperation. Having people enlightened about the importance of utilizing renewable energy, and the dangers of using fossil fuels such as oil and coal imposed on us and our planet, is critical.

Because of the low efficiency of panels and the amount of energy that we can produce by them is not significant, these projects need more time to become popular. So civilians have to be patient and the governments should spend sufficient time and funds to increase their knowledge and provoke novel ideas. Rules and regulations should also be simplified enough to become more understandable for public.

The public acceptance and its effects on renewable energy and particularly wind power are discussed in [50]. They proposed a 3 dimension method consisting of socio-political acceptance, market acceptance, and community acceptance. Other individuals that have influential responsibilities are the politicians who can support the renewable energy use by legislating proper policies.

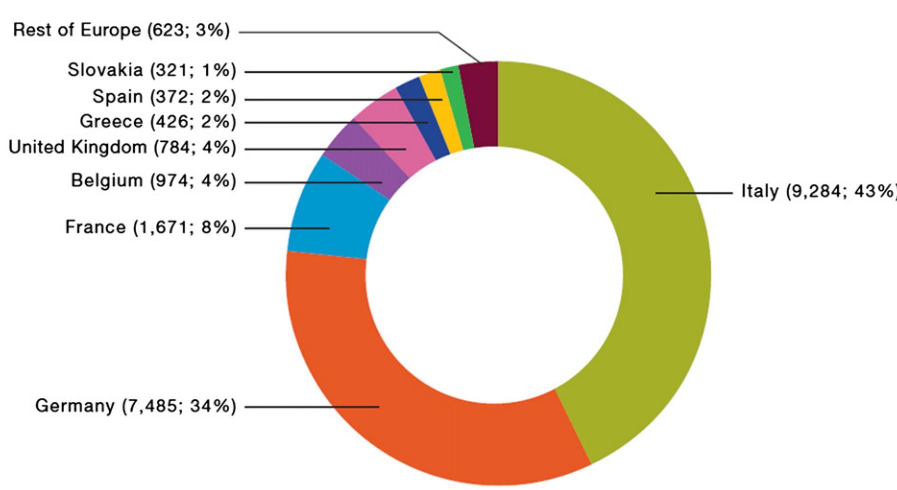

Fig. 6. Market share in Europe for the year 2011 (MW; %) [38].

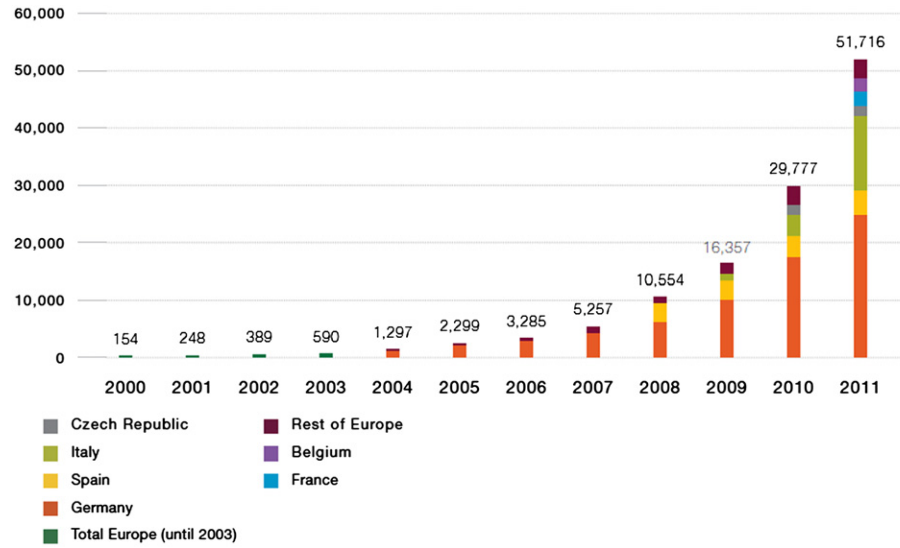

Fig. 7. Progress of cumulative installed capacity in Europe from 2000 to 2011 (MW) [38].

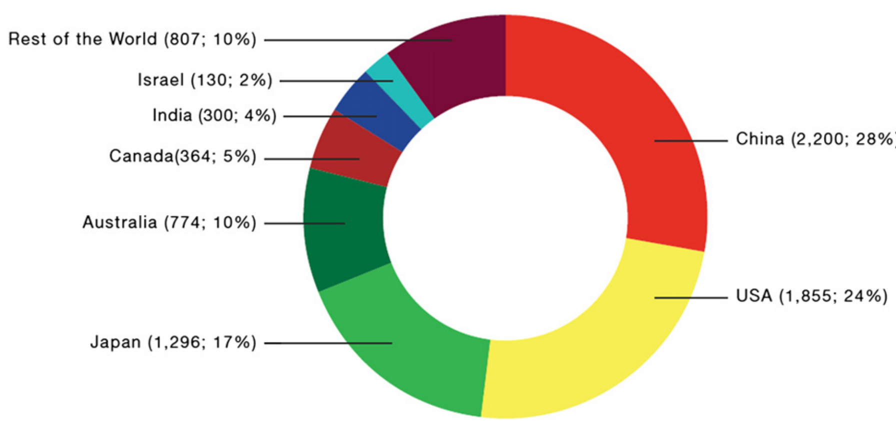

Fig. 8. Market share outside Europe in the year 2011 (MW; %) [38].

In [51], authors studied the impact of public point of view on 3 major types of renewable energy: PV, wind, and biomass. They considered different factors such as contributing people in planning, implementation processes, overall knowledge of supportive programs and financial aiding as crucial factors in public acceptance and they concluded that although the society has a positive idea about utilizing renewable energy but for obtaining further achievements, this knowledge should be increased.

The central role of public acceptance is acknowledged in many articles. After emphasizing the importance of public view in transition from old technologies to new ones like micro-generation including PV cells in buildings, Sauter and Watson [52] stated that not enough researches or activities have been carried out in this area and specifically suggested more study and data gathering on the public attitudes changes.

Heras-Saizarbitoria et al. [23] argue about this issue especially in Spain. It is considered that by improving media coverage about economic and environmental benefits of renewable sources between 2004 and 2010, Spain projects developed much faster and it holds the second position after Germany in Europe. We can also find that even with governmental support, without public acceptance, the whole project will be seriously in jeopardy.

Mannheim project showed that increasing public knowledge is vital to achieve social acceptance and it needs more effort than expected [53].

2.3. *Economic barriers*

Maybe it is the biggest barrier that hinders our goals. Without government collaborations, projects will definitely fail. The important influence of strong policy making and enough financial incentives and supports such as loans with low interests and long-term durability, subsidies and lower taxes for conducting progressive BIPV projects are mentioned in different studies [54,55]. Investing on BIPV systems is a long term investment and its best result will be revealed 20 years later. Thus, convincing companies and people to work on this investment depends on the government's power and concerns.

Many studies have attempted to compare economic feasibility of renewable energy and conventional methods of electricity generation. During this procedure some important economic factors like loan term, system initial costs and financing were thoroughly evaluated. It was discussed that programs and policies should be long-standing and governments should definitely provide maintainable incentives.

Chua and Oh [55] presented history and structure of governmental and non-governmental organizations (NGOs) who are participating in energy policy making and action plans in Malaysia. The Malaysian PV Industry Association (MPIA) is the key supplier in solar PV development in Malaysia. MPIA was founded in May 2006 to represent, develop and support the growing solar

PV industry in Malaysia and is committed to effectiveness and sustainability of PV technology implementation. In Malaysia, two different but coordinated governmental sectors work in electricity and gas supply industry; the Ministry of Energy, Green Technology and Water, and the Energy Commission (EC) [55]. Different solar programs are described in this article such as SURIA 1000 program or SURIA for Developers program, and total investments or financial encouragement for these projects is reviewed. For instance, around 1 million dollars investment was considered as financial incentives for The SURIA for Developers program.

Zahedi [56] has presented the major elements that we have to consider for determining grid-connected PV costs such as operation and maintenance costs, amount of radiation, period of loan payment and as we mentioned before governmental financial support. He frequently refers to the Australian Government which is really generous and provides admirable motivations. Nevertheless, due to some reasons the project did not work out and become popular.

In [57], the presence of PV systems in poultry industry in Tennessee has been studied and the importance of financial incentives was confirmed through legislation of state and federal funds granted to local poultry stakeholders. The amount of one of these grants is 40% of the total cost for installed solar PV systems ranging from $5000 to $75,000.

Rickerson et al. [58] considered financing a strong obstacle in front of Small Power Producer (SPP) program in Tanzania. Since Tanzanian banks are unfamiliar with renewable energy advantages, SPP does not find an adequate amount of financial support and usual loans with high interests and short returning time are not truly helpful.

Since numerous technical issues raised when BIPV systems become connected to the grid (which will be comprehensively discussed and reviewed in the next section) and also sometimes the local grid has specific and finite capability in short times of accepting new BIPV systems, self-consumption absorb more attentions as a solution. Financial supports and incentives are also important in competitiveness of self-consumption concept. According to [59], only Germany and Italy had financial supportive schemes for self-consumption. In Germany, these supports were only restricted to BIPV systems below 500 KW.

2.4. Technical barriers

In the following, the technical barriers are mentioned. Some of them are common between BIPV and any other grid-connected systems such as power losses and cell's components scarcity whereas the others such as architectural considerations are specific to BIPV. Not necessarily, all of these barriers can be removed by single solitary branch of knowledge but rather it needs interdisciplinary efforts.

2.4.1. Power losses

Different parameters cause power loss such as voltage drop in DC cables and protection diodes, pollution particles in the air, clouds, dirt, shading (by trees and buildings, as well as reciprocal effect of PV cells alignment), the variation in solar radiation and angle of panels [19,60–62]. A passing cloud can partially or entirely shut down the solar generation if it spreads shadow over a large area of PV cells [62].

It is not possible to simulate some of these factors by software. So to have an estimation of lost power we have to work on the experimental data.

Partial shading is responsible for 5% to 10% of power losses in BIPV systems [63]. It could damage the PV cells as well. This phenomenon is called hot spot and occurred when shaded cell cannot operate with the string current like other cells in a module. So instead of generating power, power dissipates through it and this causes heating side effect. Bypass diodes might be used to protect cells from this phenomenon.

In [64], the authors mentioned that module irregularities (such as cracks presence) could cause issues which have similar characteristics to partial shading.

Due to easier maintenance and lesser initial cost, usually BIPV systems are immutable tilt panels. However, some articles argued that optimized tilt and angles have significant effect on solar panels outputs [65]. In [66], a semiannually-fixed tilt formation has been suggested (i.e. it changes twice a year for optimized performance in summer and winter seasons) and the findings showed increment of energy by 5.8% over the year. This increment might be more up to 15.6% during summer.

2.4.2. Power quality

Power quality can be defined by different parameters such as harmonics, voltage, and frequency variations [19]. Power quality can be lowered mainly in high penetration situations. Connecting the different small generators to a grid can decrease the supply quality and jeopardizes the balance of power systems especially in connected points [54,61,62].

Inverters are biggest cause of harmonics in PV systems but it is mentioned that with good design and utilizing new inverters this could be nothing to worry about. Harmonics might be caused occasionally by the load itself as well.

Harmonics from PV power generation can be affected by other PV systems. So during the system design, it is important to evaluate the whole inclination of all generators which are connected to the grid [67].

Some sources declare that harmonics caused by high PV penetration will not be serious threat and do not have severe impacts on the grid voltage distortion. Using modern inverters is one solution to consider [62,68]. Utilizing harmonic filters and power conditioning systems can remove the major part of harmonics from PV outputs.

Voltage variations phenomenon caused by PV systems has been discussed in different articles and different methods such as inverter reactive power injection, switched capacitor, and on-load tap changer are proposed [69]. It is suggested that if PV penetration is under 20%, the fluctuation is not significant. By simulation, it is concluded that concentration should be amplified in low voltage grids. A couple of solutions have been put forward:

1. Utilizing battery storage which is an expensive solution. This method was also studied by [70–72].
2. Utilizing PV reactive power support through inverters [73,74].

Unbalanced relationship between supply and demand might cause deviation from system nominal frequency and particularly in high penetration PV systems could make control difficulties [75].

2.4.3. Inverters analysis

Maybe the most complicated equipment in PV systems is the inverter and its function, output and efficiency. Maximum Power Point Tracking (MPPT) efficiency is the common factor for assessing the inverters' function. MPPT efficiency is difficult to measure because it depends on both inverters' internal characteristics and external parameters such as PV cells, obtained radiation, and climate [76,77].

In critical situation especially during partial shading condition, having a strong MPPT algorithm is very crucial and by considering

the nature of BIPV, the risk of shading is high. In [64], the authors discussed different and most common algorithms in MPPT. They concluded that especially during partial shading, a combined method of different evolutionary algorithms such as PSO and artificial neural network (for choosing the appropriate amount of population size etc.) could be the best solution. The following diagram (see Fig. 10) shows different and usual methods for MPPT [64].

2.4.4. Cost/efficiency ratio

Although the initial cost of PV cells has decreased significantly during past years, the most important technical issue in PV cells is still their low efficiency as compared to their cost. Since 1980, the photovoltaic panels cost per each W experienced a significant drop from $30/W to $3/W [16]. Fig. 11 presents the PV production and cost per watt in the last 30 years before 2005 [68]. The cost of installation in PV cells has also decreased from $16,000/kW in 1992 to $6000/kW in 2008 [8]. The efficiency of thin films PV cells ranges from 4% to 12% and the efficiency of crystalline type PV cells is below 22% [78,79].

Besides that, according to [80], the decrement of production cost is from $33.4/W on 1979 to $1.8/W in the year 2010 (see Fig. 12).

2.4.5. Cell's components scarcity

The recent growth in PV markets needs more investments and new mineral sources for major components of PV cells such as silicon, cadmium and tellurium. At this time, 93.5% of solar cells are produced from silicon wafers [81]. Demand for silicon for solar cells is expected to increase from 41,000 t in 2006 to 400,000 t in 2015 [32]. Our current sources of these elements are not abundant so they are becoming rare and expensive each day [8,62]. Thin film solar cells may get benefit from this condition. Fig. 13 shows the growth rate of thin film solar cells production. Fig. 14 shows crystalline and thin-film technologies shares of BIPV market.

Silicon is needed as well in another growing industry which is semiconductor. The initial signs of silicon shortage occurred firstly around 2006. Van Sark et al. [81] declared that due to the ability to produce thinner and more efficient wafers, it is possible

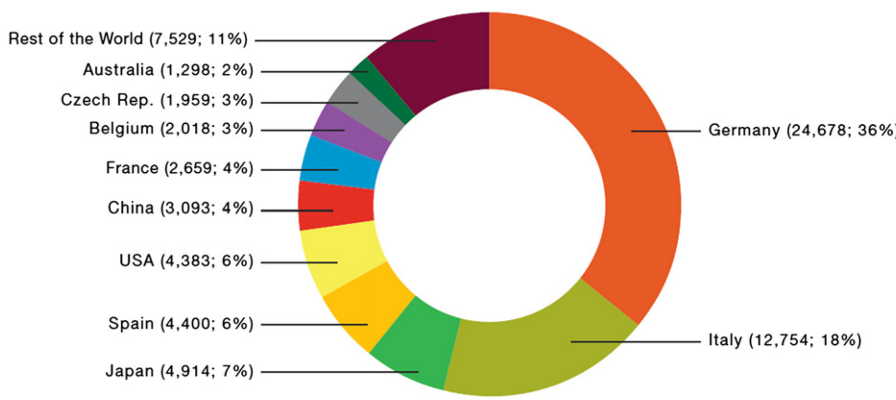

Fig. 9. Global cumulative installed capacity share in the year 2011 (MW; %) [38].

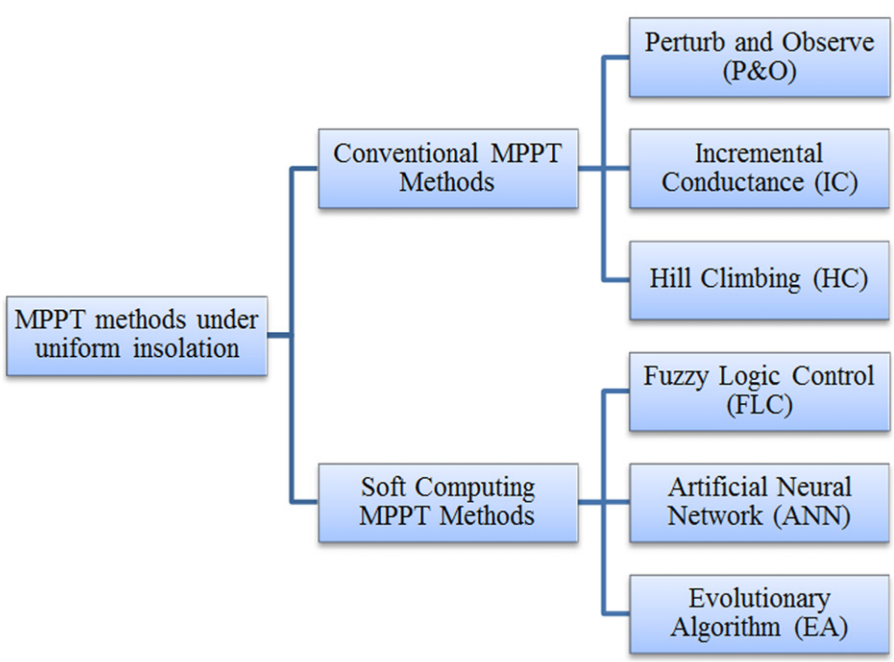

Fig. 10. Common MPPT algorithms.

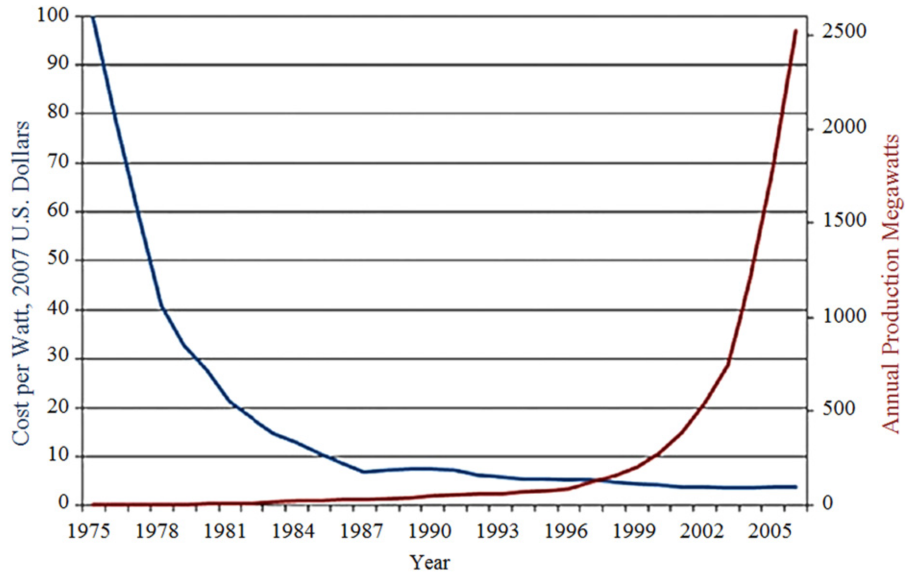

Fig. 11. World's PV production and cost per watt in the last 30 years [68].

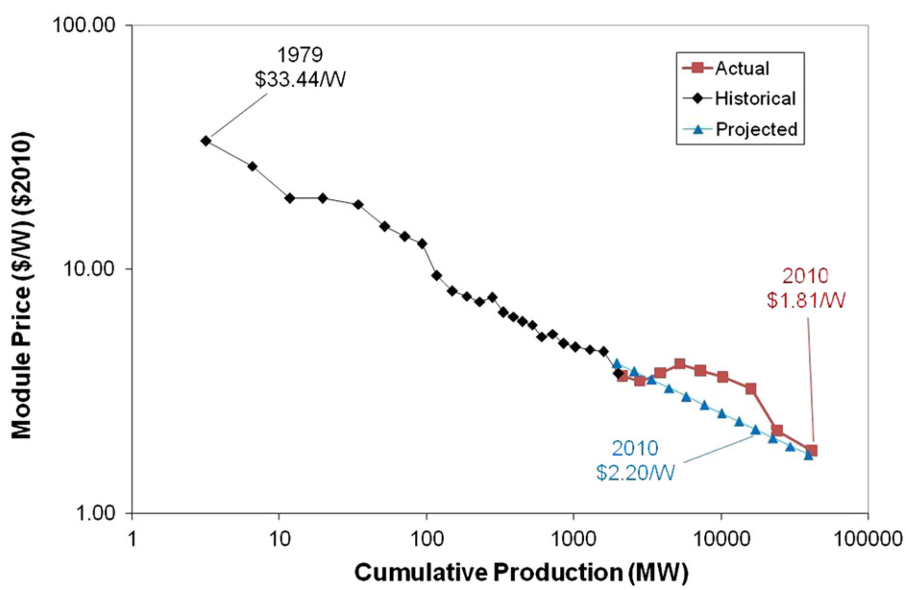

Fig. 12. Cost reduction of modules production in the period 1979–2010 [80].

to increase the solar cells production productivity. They stated that the amount of used silicon in 2003 considering 14% efficiency at that time and 320 μm thickness was 14 t per MWp. However by improving the industry, in the year 2010, the 17% efficiency and 150 μm wafers were produced. So the amount of used silicon decreased to almost 7.5 t per MWp. The progress of silicon feedstock production during 2003–2010 is presented in Fig. 15.

2.4.6. Architectural considerations

A number of investigations have discussed parameters which should be considered by architects during design stage to reach the zero energy buildings [83]. The idea is to have buildings which are not only energy efficient but also should be capable of generating their own needed energy as much as possible through solar systems. Due to "Directive 2010/31/EU" document, by the end of 2020 all new buildings should be net-zero-energy type [84]. Different parameters should be considered by architects such as energy performance, facade or glazing, and most of these parameters have to be checked during the preliminary design phase which is in the architectural realm [85]. US Department of Energy (Comment: Which country?) [86] prepared a list of building energy software tools and categorize them in different ways. According to [87], less than 40 tools of 392 ones listed in this directory are prepared for architects and cover initial design phases. A decision tool called ZEBO is introduced to help in residential building design where PV is used.

"Subtask B" section of "IEA SHC Task 41" document prepared by 14 countries' experts focuses more on possible barriers which architects may encounter while they want to consider solar systems in their designs. Main ideas of the document are to analyze current tools capabilities and barriers, and architects' needs and methods used during building performance analysis

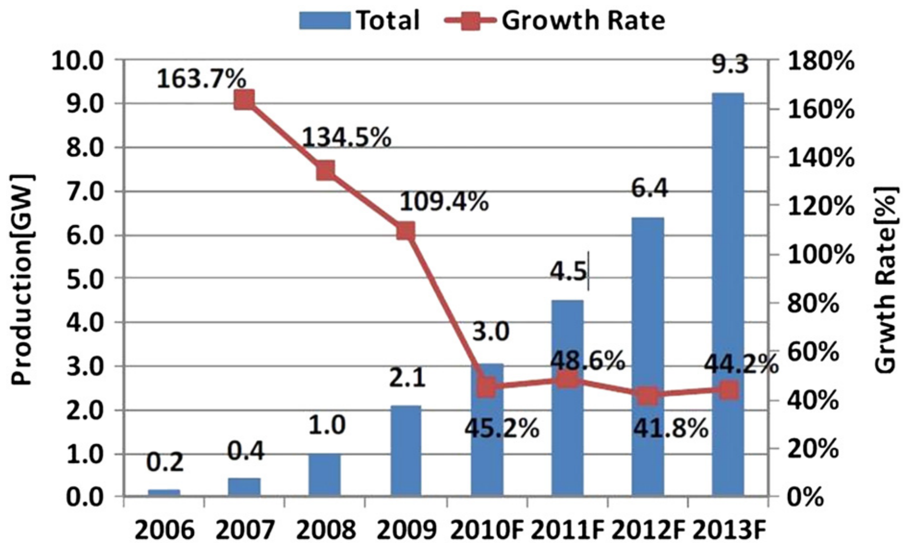

Fig. 13. Global growth rate of thin film solar cells production [82].

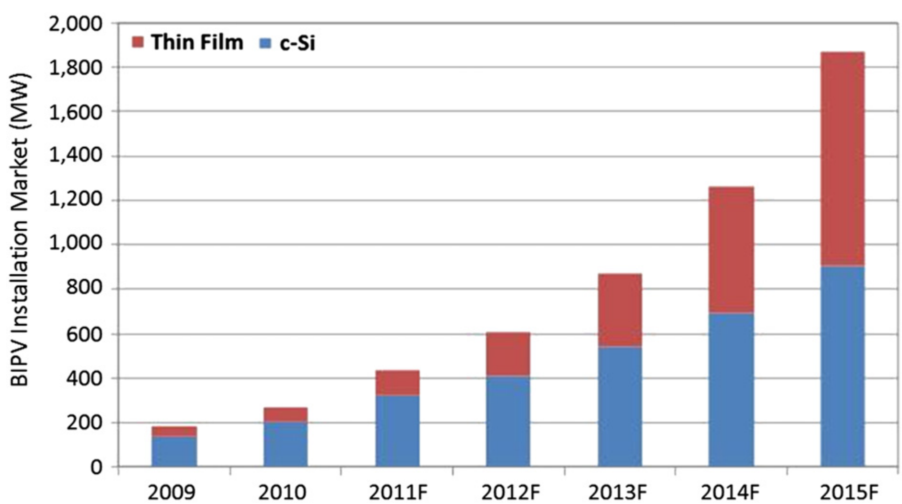

Fig. 14. Crystalline and thin-film technologies shares of BIPV market [82].

and simulation [88]. The architects can use these tools in design phases to examine the truth of their ideas and later to present them to customers. Horvat et al. [85] reviewed this subtask and tools and concluded that major necessities now are software which is not only more capable in design of building complex, since nowadays most buildings exist in urban areas, but also more user-friendly and reliable from 3D modeling point of view.

In [84], the authors also emphasized that considering building individually is not sufficient. The correct perspective in Net Zero Energy Buildings (NZEB) is to presume buildings and their environments as a larger system together.

2.4.7. Islanding

A condition in which a portion of the utility system that contains both load and distributed resources remains energized while isolated from the reminder of the utility system is called islanding [89]. In other words some parts of the grid become disconnected from main supply and considered disconnected completely while the loads are flowing by PV supply [60].This problem could damage equipment or even cause a death risk for workers who are working in this section.

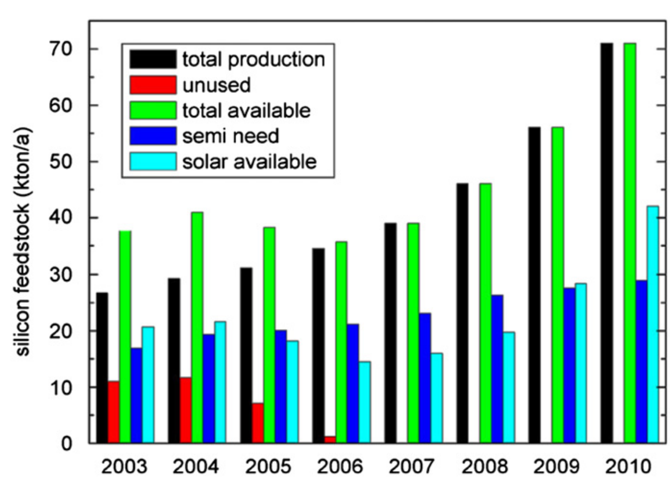

Fig. 15. Progress of silicon feedstock production 2003–2010 [81].

It is suggested that unintentional islanding should be detected in less than 2 s [90]. Different methods based on grid equipment, cost and other factors have been developed for islanding

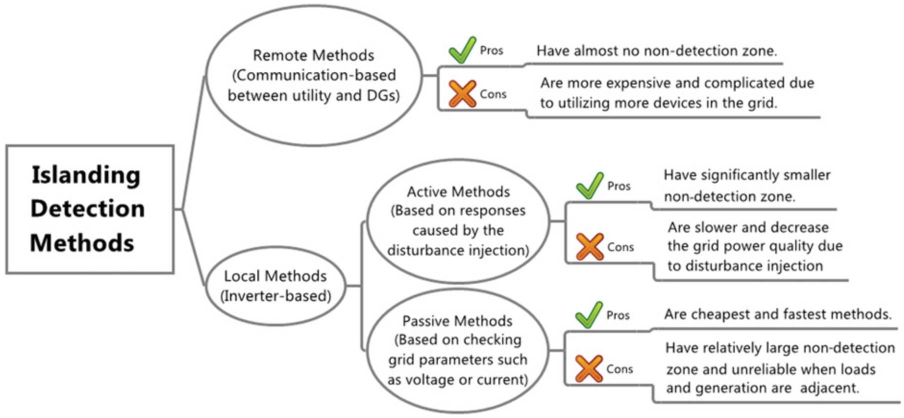

Fig. 16. Islanding detection methods review.

detection. Based on [91–93], Fig. 16 represents a brief overview of these methods, their types and pros and cons.

3. Conclusions

The importance of changing our current limited, polluting and anti-environmental methods of generating electricity in order to save our world and to guarantee our future's wellbeing is not hidden to anyone. Unfortunately any encompassing method which can completely cope with our present situation has not been proposed yet. Among renewable energy sources, it seems that solar energy has this potential to solve our problems in the future. Its abundance, accessibility, being environmentally friendly and recent and ongoing development in designing and manufacturing cells to make them less costly and other factors, make BIPV a reasonable alternative for long-term supply of energy that we can depend upon. However, number of barriers and hindrances are to be faced in order to ensure successful implementation of any BIPV projects. In this paper, the barriers are categorized into four main groups. The duties of governments to prepare supportive laws, policies and financial aids as well as defining suitable FiT rate are mentioned as critical considerations. In addition, people's positive attitudes and their cooperation are of unimaginable significance. Also improving the engineering design in order to enhance the coordination between the conventional distribution network and the distributed generators, producing cells with better efficiency and maintaining power quality through more sophisticated controlling systems and devices are some of the technical issues explained. Last but not the least, with all new progressions; we are inclined to set our hearts to obtain a more satisfactory cost/efficiency ratio.

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